NNA11369016Q

Statement of Work
Mars EDL TPS Materials Procurement
Round 1 – Development (Phase 2)

Mars Entry, Descent and Landing
Technology Development Project

January 7, 2011

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California

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1.0 INTRODUCTION

1.1 GENERAL INFORMATION

In 2009 the Exploration Technology Development Program (ETDP) established the Entry, Descent and Landing Technology Development Project (EDL TDP), to be managed programmatically at Langley Research Center (LaRC) and technically at Ames Research Center (ARC). The purpose of the project is to further the technologies required to land heavy (~40 metric ton) masses on Mars to facilitate exploration. The EDL TDP contains three technical elements. They are:

1) Thermal Protection Systems (TPS) development
2) Modeling and Tools (MAT) development
3) Supersonic Retropropulsion (SRP) development

The primary goals of the EDL TDP TPS element is to design and develop TPS materials capable of withstanding the severe aerothermal loads associated with aerocapture and entry into the Martian atmosphere while significantly decreasing the TPS mass fraction contribution to the entry system. Significant advancements in TPS materials technology are needed in order to enable heavy mass payloads to be successfully landed on the Martian surface for robotic precursor and subsequent human exploration missions.

The EDL TDP TPS element is further divided into two different TPS concepts for Mars EDL those being:

1) Rigid TPS for a mid L/D (Lift/Drag) aeroshell
2) Flexible TPS for a deployable aerodynamic decelerator

In early 2010 the EDL TDP solicited proposals for Round 1 screening of rigid and flexible TPS. Eight (8) TPS materials were subsequently evaluated during the Round 1 screening phase, and several of those materials were recommended for a follow on development phase. This Statement of Work (SOW) will focus on that development phase – Round 1 Development selection and screening of rigid TPS concepts for a mid L/D rigid aeroshell. The specified requirements for the concept rigid system are provided within the narrative and tables below. This SOW will consider materials at any technology readiness level (TRL).

1.2 MID L/D RIGID AEROSHELL INFORMATION

The rigid aeroshell TPS concept is required to survive two heating pulses, the first during aerocapture into Mars orbit, and the second during entry into the Mars atmosphere for descent and landing onto the Mars surface. In addition, this rigid aeroshell TPS concept is required to minimize TPS mass in order to maximize payload mass. The aerocapture and entry phases could be separated by as much as six months. The mid L/D concept consists of an approximately 10 meter diameter by 30 meter long body with three general regions of thermal heating: the backshell (lowest heating), nose cone (mid heating), and heatshield (highest heating). Figure 1 depicts the mid L/D rigid aeroshell TPS concept. This SOW focuses only on the heatshield, or windward side of the mid L/D body, where the highest heating will occur, and seeks any TPS concept capable of handling long duration heat load during aerocapture followed by entry from Mars orbit. Examples of TPS concepts envisioned by the NASA project team for the rigid aeroshell application include multilayer (e.g., ablator over insulator or ablator over ablator), warm structure, and conformable systems. Non-tiled (monolithic) TPS concepts are strongly preferred.

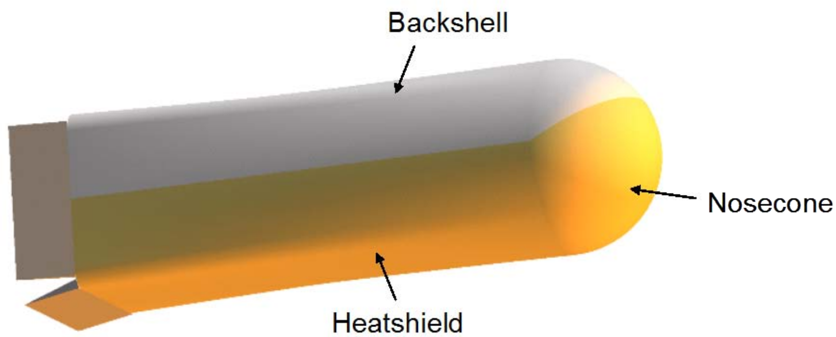

Figure 1: Mid L/D rigid aeroshell TPS concept.

Upon arrival at Mars via a trans-Mars injection from Low Earth Orbit (LEO), the mid L/D vehicle undergoes an aerocapture maneuver to both reduce the vehicle velocity and bring it into Mars orbit. Estimated heating rates for the aerocapture maneuver are shown in the table below. Once in Mars orbit (up to six months), the mid L/D vehicle will then enter the Mars atmosphere at hypersonic velocities, and the heatshield will be jettisoned at approximately M=5. **Table 1** shows the estimated peak entry environments, and Figure 2 shows the heating histories for the aerocapture and entry

Table 1: Peak aerothermal entry environments for mid L/D rigid aeroshell.

Aerothermal Entry Environments-Rigid	
Peak Heat Rate (Aerocapture)	500 W/cm^2
Peak Aerocapture Heat Rate (Convection)	450 W/cm^2
Peak Aerocapture Heat Rate (Radiation)	130 W/cm^2
Peak Heat Rate (Entry)	130 W/cm^2
Peak Entry Heat Rate (Convection)	130 W/cm^2
Peak Entry Heat Rate (Radiation)	20 W/cm^2
Total Heat Load (Aerocapture + Entry)	80 kJ/cm^2
Heat Load (Aerocapture)	55 kJ/cm^2
Heat Load (Entry)	25 kJ/cm^2
Peak Pressure	
Peak Pressure (Aerocapture)	45 kPa
Peak Pressure (Entry)	25 kPa
Peak Shear Force	
Peak Shear Force (Aerocapture)	700 Pa
Peak Shear Force (Entry)	300 Pa

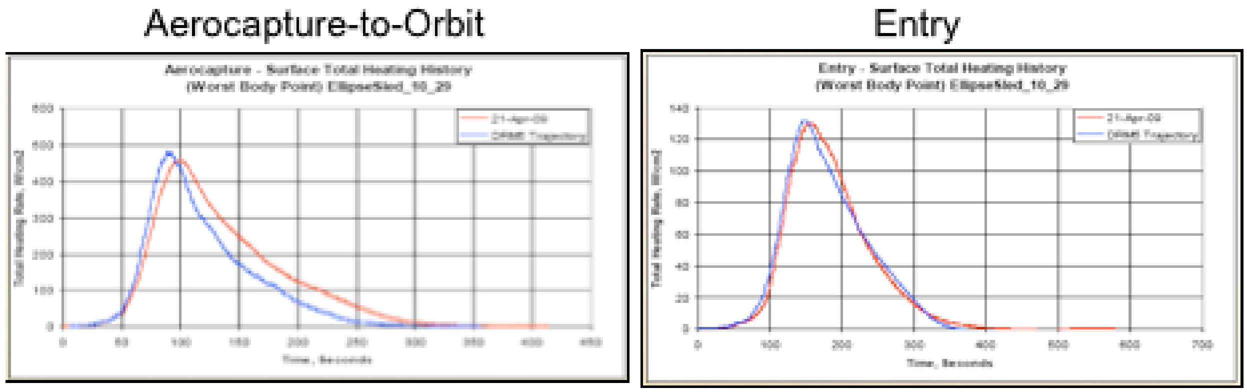

Figure 2: Heating time histories for mid-L/D rigid aeroshell.

Preliminary analyses of heatshield requirements have been performed using the aerocapture and entry trajectories as driving boundary conditions. Using Phenolic Impregnated Carbon Ablator (PICA), with a density of 0.28 g/cm3, as the baseline material for the heatshield, these analyses showed that a margined thickness of 14cm would be required to protect the bondline between the heatshield and the structure. Further analyses showed that this thickness would result in a marked reduction in the delivered payload due to the mass of the heatshield. The EDL TDP is interested in material systems that can meet the heating requirements with a threshold of a 25% reduction in mass and a goal of 50% reduction in the mass over PICA.

This procurement will consist of acquiring materials for Round 1 development (Phase 2) tests of multiple TPS materials within a detailed trade study framework in order to advance promising rigid ablator material concepts to TRL 5 by FY14.

1.3 SCOPE AND OBJECTIVES

This Statement of Work (SOW) defines the requirements for the Round 1 procurement of rigid ablator materials to support the EDL TDP Phase 2 development of materials and concepts for Mars heavy landing mass missions.

In following with the previous screening approach, NASA anticipates continuing a phased acquisition with down-selection procedures for subsequent rounds in accordance with NASA FAR Subpart 1817.73 Phased Acquisitions. This SOW describes the requirements for the Round 1 Development Phase, or Phase 2 of TPS screening. Competitions for subsequent phases will build on the testing results of previous phases. The award criteria for subsequent phases will include demonstrated completion of specified previous phase requirements.

The Government expects that only contractors selected for a screening phase will be capable of successfully competing for the subsequent development phases, and proposals for development phases following a round of screening will be requested from these contractors selected for further development and maturation. Notwithstanding the expectation that only the screening phase contractors will be capable of successfully competing for the subsequent development and maturation phases, proposals from all responsible sources submitted by the specified due date will be considered for award. In order to contend for subsequent development phase awards, however, such prospective offerors must demonstrate design maturity equivalent to that of the prior phase contractors. Failure to fully and completely demonstrate the appropriate level of design maturity may render the proposal unacceptable with no further consideration for contract award.

In addition to soliciting TPS materials for development by NASA, an objective of this solicitation is to request detailed information about the proposed TPS material in relation to the material/system TRL, as defined in **Table 2**.

Table 2: NASA TRL guidelines.

TRL	Guideline
TRL-1	Basic principles observed and reported.
TRL-2	Technological concept and/or application formulated, lab samples made, environment for possible application defined.
TRL-3	Analytical and experimental critical function and/or characteristic proof-of-concept, initial test; i.e., arc jet, thermal cycling demonstrate proof-of-concept.
TRL-4	Component and/or breadboard validation in laboratory environment; detailed testing of materials at temperature and under appropriate atmosphere.
TRL-5	Component and/or breadboard validation in relevant environment, such as arc jet for thermal and structural test at temperature environment.
TRL-6	System/subsystem model or prototype demonstration in a relevant environment (ground or space) to demonstrate flight readiness.

In the solicitation response, the vendor shall address each of the following descriptions in the subsections below:

1. System Description

Describe the candidate TPS system, including thermal protection materials, surface coatings, bonding agents or adhesives, insulating layers, surface encapsulation or any other substance or mechanism between the outer mold line and the carrier structure. Present conceptual material stackups of all TPS components. For each component material, complete (to the fullest extent possible) the Table 4 material properties template for known values; if unknown, state "unknown". Cite the basis for all material property values (measured or inferred). If possible, provide test reports that document the material property testing approach and results. If test reports are unavailable references should be provided if possible. If available, provide details of complete ground testing and flight heritage for the system and individual components, particularly at conditions of peak heating rate shown in Table 1.

2. Design Rationale

Provide rationale for the TPS material being discussed. Explain the basis for suggesting the system as a candidate for further development and application for Mars EDL.

3. Performance Testing

If available, provide any study results or data that supports the TPS materials and systems ability to withstand operating environments including on-orbit radiation and thermal cycling.

4. TPS Scale-Up

Describe the scale-up approach for low TRL materials to be advanced and the conceptual approach of applying/implementing the proposed TPS over a large rigid aeroshell as shown in Figure 1. Discuss any known or perceived issues with scale-up (e.g. – current lab equipment limits size of TPS samples to X m^2 and X mm thick or processing of TPS beyond X meters in length requires development of new technology Y).

1.4 DELIVERABLES

1.4.1 Rigid Deliverables

A description of rigid hardware deliverables for Round 1 Development is provided in Table 3. The EDL TDP will select up to 3 rigid ablator systems. Vendors shall deliver 13x13-inch panels of the material systems, which will be machined by NASA for various screening tests that will include thermal, aerothermal, ablation response in NASA arcjets (ARC or JSC), and structural tests. Relevant material orientations, such as ribbon direction for ablators that use honeycomb core, should be marked clearly on the billet. The anticipated procurement amount is ~$4000-$6000 per billet. Note: Materials costing more than the anticipated amount will be considered but the actual number of specimens procured may be limited by program funding.

Table 3: Hardware deliverables for Round 2 Rigid TPS screening.

Material Type	Specimen Type	Quantity of Specimens	Specimen Thickness	Delivery Date
Required TPS	Panel 13x13-inch Square	3	Vendor Defined	March 30, 2011*
Optional TPS	Panel 13x13-inch Square	2 Priced Individually	Vendor Defined	March 30, 2011*

*Note: If the requested delivery date cannot be met, suggest the earliest date a delivery will be possible. Not to exceed April 30, 2011. More or less quantity may be ordered depending upon price and NASA resources.

Vendors should supply a billet with minimum thickness necessary to make a 13-inch square panel weighing 1550±100 grams. This number is based on the time required to raise the back face temperature of the baseline specimen Phenolic Impregnated Carbon Ablator (PICA) to 250ºC when subjected to a heat flux of 450-500 W/cm^2 for 50-60 seconds. Based on PICA's density, it has been sized for a thickness of 2.0 inches (5.08 cm). For a 13-inch square, the resulting PICA mass is 1550±100 grams.

Aerothermal screening specimens will be machined from the vendor supplied billet and will be thermally exposed to heating in either air and/or CO_2 / N_2 arc-heated flows in the arcjet facilities at NASA (either ARC or JSC). 4-inch diameter IsoQ (An IsoQ model has an outer mold line curvature radius equal to the diameter of the specimen – provides for more uniform pressure and heating across surface of test model) specimens will be machined by NASA from the vendor supplied billets. IsoQ models will be instrumented with in-depth thermocouple plugs to acquire through the thickness thermal response of candidate TPS materials. This data will be used to begin developing mid-fidelity thermal response models of the TPS materials under consideration.

Structural screening specimens will be machined from the vendor supplied billet, and will consist of tensile and/or bend tests. Tensile tests will be bonded to aluminum blocks and bend tests will be bonded to an aluminum substrate and subjected to three or four-point bend tests oriented to put the outer surface of the ablator in tension. Again, the baseline comparison coupon will be built from Phenolic Impregnated Carbon Ablator (PICA) with a thickness of 2.0-inch (5.08 cm). NASA will perform the bonding operation with adhesives suitable for the stress levels anticipated during testing. If the vendor is aware of potential bonding issues, such as surface prep requirements or incompatibilities, the vendor should inform NASA so that NASA and the vendor can determine a suitable bonding process.

1.4.2 General Deliverable Requirements

All delivered specimens must be accompanied by a Material Safety Data Sheet (MSDS) for all materials used in manufacturing the specimen (reference FAR clause 52.223-3 Hazardous Material Identification and Material Safety Data (Alt I).

If available, the vendor will provide any available material properties data for their concept materials. A suggested list of material properties is shown in Table 4. The properties listed in Table 4 do not constitute a comprehensive set. Respondents are free to add other important properties as appropriate, and omit properties that are not relevant for a particular type or component of a particular TPS. For properties that vary as a function of material direction or environmental parameters (e.g. temperature, pressure) provide a table of the property values as a function of all governing parameters. Representative stress / strain curves in the in-plane and TTT directions are requested, if available.

The basis, or source, for each value must be provided, e.g. test measurements, analytical predictions and published data. If possible, provide test reports that document the material property testing approach and results. If test reports are unavailable references should be provided if possible. Supply a separate set of tables for each material, if proposed TPS has multiple layers.

Table 4: Material properties suggested for inclusion in RFP response.

Vendor Name		
Concept Design		
Material		
TRL for Material		
Material Property	**Nominal Value**	**Basis/source**
Physical and Chemical		
Virgin material density (g/m^3)		
Char density (g/m^3)		
Virgin material composition (constituents and mass fractions)		
Heat of formation, virgin material (J/g)		
Heat of formation, char (J/g)		
Elemental composition, virgin material		
Elemental composition, char		
Thermal Gravimetric Analysis (TGA) data in inert gas		
Porosity, virgin material (%)		
Porosity, char (%)		
Recombination coefficient for oxygen		
Recombination coefficient for carbon dioxide		
Catalytic efficiency in dissociated carbon dioxide		
Thermal		
Specific heat, virgin material (J/g-K)		
Specific heat, char (J/g-K)		
Thermal conductivity, virgin material (W/m-K)		
Thermal conductivity, char (W/m-K)		
Coefficient of thermal expansion, virgin material (cm/cm/°C)		
Coefficient of thermal expansion, char (cm/cm/°C)		
Optical		
Total hemispherical emissivity, virgin material		
Total hemispherical emissivity, char		
Spectral reflectivity, virgin material		
Spectral reflectivity, char		
Structural		
Tensile modulus (kPa)		
Compressive modulus (kPa)		
Shear modulus (kPa)		
Ultimate tensile strength (kPa)		
Ultimate compressive strength (kPa)		
Ultimate shear strength (kPa)		

If available, vendors are also asked to provide information on material strain to failure, and stress vs. strain plots.

2.0 APPLICABLE DOCUMENTS

All applicable documents, which form a part of this contract, are listed herein. The applicable version shall be the current version at the time of contract award. In the event of a conflict between applicable documents and the contents of this SOW, the SOW shall take precedence.

3.0 TASK REQUIREMENTS

3.1 MANAGEMENT, COST AND CONTROLS

3.1.1 General

NASA’s Contracting Officer Technical Representative (COTR) will serve as the primary point of contact between NASA and the Contractor for all technical and programmatic issues related to this SOW. The NASA Contracting Officer (CO) will serve as the primary contact for all contractual issues.

a) The Contractor shall provide management of all resources, schedule, engineering design and development, procurement, quality control, and documentation control to deliver the services and products required.

b) The Contractor shall designate a single individual who will be given full responsibility and authority to manage and administer all aspects of the work specified in this SOW, and ensure that all objectives are accomplished within schedule and cost constraints.

c) The Contractor shall designate a single individual who shall serve as the point of contact with the COTR for all technical and programmatic aspects of the contract.

d) The Contractor shall designate a single individual who shall serve as the point of contact with the CO for all contractual aspects of the contract.

3.1.2 Schedule

During all rounds of this phased acquisition process, the EDL TDP will screen, test and develop materials capable of withstanding the aerothermal environments expected during aerothermal capture and entry at Mars. For the rigid ablator concepts, NASA anticipates two material systems to mature to TRL=5 by the end of the phased acquisition process planned for FY2014. The current procurement addressed in this SOW, Development Round 1, is outlined with a box as shown in Figure 3.

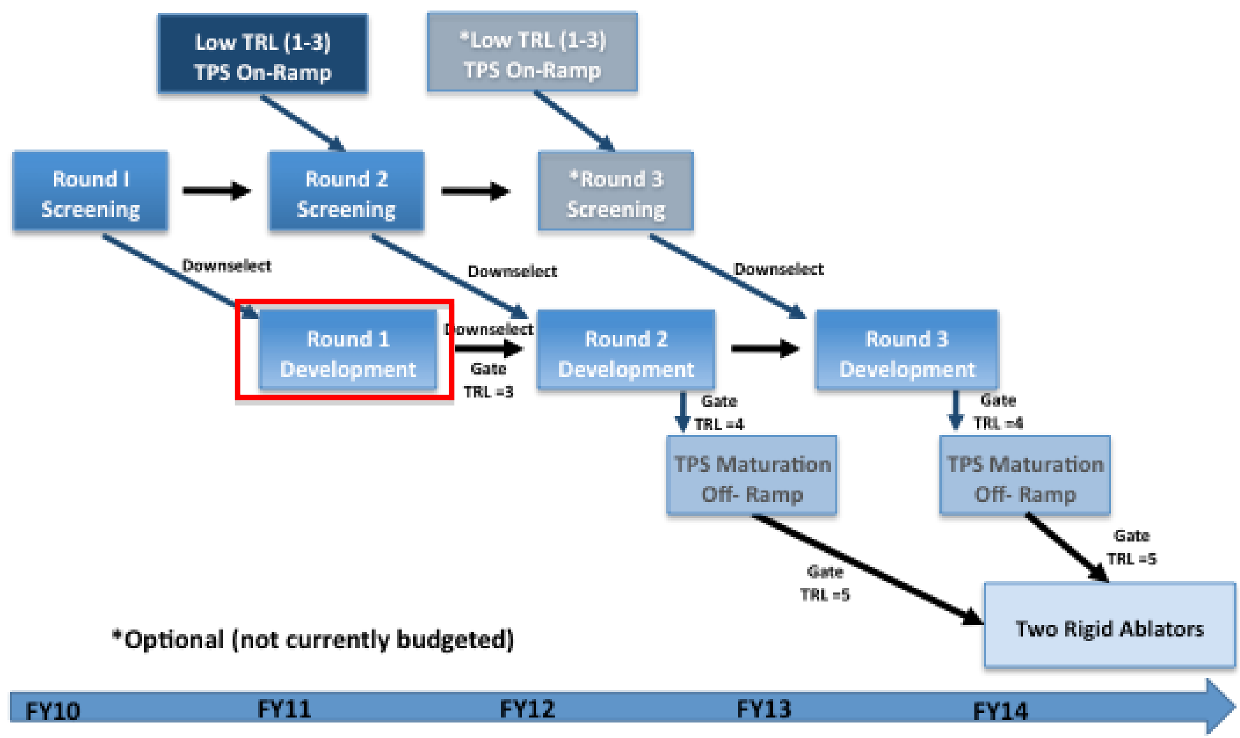

Figure 3: Rigid ablator development schedule.

Based on Round 1 Phase 1 screening, the EDL TPS Element developed the criteria shown in Table 5 to evaluate the rigid TPS material concepts that were tested during the Phase 1 screening campaign. A similar set of criteria will be used for the downselect process in the Round 1 Phase 2 Development.

Table 5: Downselect evaluation criteria for Rigid TPS.

Criteria	Mandatory (Y=1, N=0)	Weight (%)	Scale
Thermal Performance	1	30	3=Good Performance 1=Poor Performance
Structural Performance	1	20	3=Good Performance 1=Poor Performance
Areal Mass	0	10	3=Meets Required Areal Mass 1=Exceeds Required Areal Mass
Monolithic Design Possible	0	10	1=Yes 0=No
Robustness	1	10	3=Most Robust 1=Least Robust
Optimizability	1	10	1=Yes 0=No
Adaptability to Various Vehicle Designs	0	10	3=Most Adaptable 1=Least Adaptable

In addition to the downselect evaluation criteria described in Table 5, TPS vendors participating in Development Round 1 (Phase 2) will be expected to demonstrate progress towards meeting the current EDL Key Performance Parameters, as described in Table 6. Vendors are not expected to meet the goal values at this time, but should address in their proposal how they expect to meet goal values by TRL 6 (including potential facility upgrades).

Table 6 – Current Key Performance Parameters for EDL Rigid Thermal Protection Systems

KPP	Name	Description	State of the Art Value	TRL 6	
				Threshold Value	Goal Value
KPPR-1	**Areal Mass**	A metric that will allow for the evaluation of mass savings over the current state of the art. (g/cm^2)	4.0 (PICA 14-cm thickness req)	3.0 0.75*PICA	2.0 0.5*PICA
KPPR-2	**Strain to Failure**	A material property metric that will provide an indication of compliance when bonded to an underlying structure. (microstrain)	3000 PICA	4500 (~1.5*PICA)	>30000 (~3*AVCOAT)
KPPR-3	**Manufacturing Scalability**	A metric that addresses an assessment of the likelihood that the technology concept will successfully scale to the large sizes required by the mission architectures	20"x40" Max PICA tile size, 1-m Diam Cast monolithic	2-m diameter by 2-m length	4-m diameter by 4-m length, or greater
KPPR-4	**Response Model Fidelity**	Ability to reliably and repeatably predict the thermal response of the material to applied environments.	Mean: bias error 30%, time-to-peak error 30%, recession 150%	Mean: bias error <20%, time-to-peak error <20%, recession TBD	Mean: bias error <10%, time-to-peak error <10%, recession TBD

3.1.3 Data Dissemination

a) The EDL TDP will provide data originating from the Phase 2 development tests to vendors and return a portion of the post-test sample for the vendor's evaluation purposes (if requested).
b) The EDL TDP intends to publish results and data from the Phase 2 development tests in the open scientific literature. Any data dissemination restrictions or protection of proprietary information must be clearly stated in the quotation documentation provided by the vendor/contractor.

For publication purposes, vendors are requested to provide a publically releasable description of their TPS.

All information received in response to this RFP that is marked Proprietary will be handled and protected accordingly. As applicable, NASA will likely provide proprietary information to its support service contractors who are under an obligation to keep third-party proprietary information in confidence. By submitting a response to this solicitation, the responder is deemed to have consented to release of proprietary information to such NASA support service contractors.

3.2 OTHER REQUIREMENTS

3.2.1 Packaging, Handling, Storage, and Transportation

The Contractor shall provide to the COTR, at least 30 days prior to any shipment to a NASA Center, any special provisions or requirements for handling or storage of deliverable items. These may include special handling procedures, storage conditions or environments, special ground support equipment (handling fixtures, support stands or other equipment) or usage of hazardous materials.

Vendors selected for Round 1 Phase 2 Development will send their deliverable items to the following:

Rigid Materials POC:

Matt Gasch
NASA Ames Research Center
Mail Stop 234-1
Building 234 Room 211
Moffett Field, CA 94035
Tel: 650-604-5377
E-mail: matthew.j.gasch@nasa.gov

3.2.2 Post-Shipment Support

Contractor support to NASA in handling of delivered materials, preparation for tests, or post-test analysis is not anticipated. However, the Vendor may be requested by the COTR to provide post-ship support.